Ice-Albedo Feedback Process in the Arctic Ocean

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LONG-TERM GOALS

The overall goal of this proposal is to quantitatively understand the ice-albedo feedback and incorporate this understanding into large-scale models.

OBJECTIVES

To achieve the project goal, we must first determine how shortwave radiation is distributed within the ice-ocean system, then assess the effects of this distribution on the regional heat and mass balance of the ice pack. Specific objectives of this study are:

- To quantify the contribution of ice and snow processes to the surface energy balance and the ice albedo feedback (IAF) through synthesis of the SHEBA Phase 2 ice, atmosphere, and ocean data.

- To determine how shortwave radiation is partitioned between reflection, surface melting, internal heat storage, and transmission to the ocean; and how this partitioning is affected by the physical properties of the ice, snow cover, and melt ponds.

- To define the areal distribution of ice, ponds, and leads?

- To integrate floe-scale process models of IAF into a granular model of the ice cover and perform simulations of the SHEBA summer to develop aggregate-scale parameterizations for use in the GCM's ice model.

- To validate improvements in the GCM's ice model simulation of ice conditions within the SHEBA Phase 2 domain and in the larger Arctic Ocean basin.

- To ascertain the impact of the newly parameterized processes on the simulation of IAF in GCMs.

APPROACH

The goal and objectives of this program are being addressed through a combination of both data analysis and modeling. We are conducting a detailed analysis and assimilation of field observations we made during the SHEBA year. Results from this work are providing the basis for development and

testing of parameterizations and process models that will be incorporated in a discrete element model, a single grid cell GCM ice model, and the NCAR global GCM. While much of our effort is concentrated on the complex and poorly understood summer melt season, there are crucial questions related to the longer-term evolution of pressure ridge keels and connections between ice dynamics and thermodynamics. These questions require us to examine the heat and mass balance of the ice cover over the entire annual cycle.

It is critical to scale up the local and regional observations made during the SHEBA field experiment to the larger scales used in basin wide sea ice models and GCMs. For this reason, a central component of our approach is to investigate ice-albedo feedback processes on three scales: the local scale, the aggregate scale, and the large scale. At the local scale, we are examining data from the SHEBA floe and its neighbors, then are using those data to develop process models and parameterizations that treat the temporal evolution of albedo, the formation and development of melt ponds, seasonal mass changes on the top, bottom and sides of floes, and the storage and transmission of shortwave energy by the ice. At the aggregate scale, we are analyzing aerial photographs and satellite imagery to obtain time-dependent statistics on the state (e.g., concentration, pond coverage, floe size distribution) of the ice cover in a 50 km by 50 km region, centered on the ship. These statistics are being combined with results from the local studies to calculate areally-averaged quantities such as albedo, heat input to the ocean, lateral melt losses, surface melt water storage, and internal heat storage within the ice pack. These data will provide both initial conditions and a comparison for simulations using a discrete element model and a single grid cell GCM. Parameterizations will be developed and tested at the aggregate scale and then incorporated into large-scale sea ice and global climate models. Sensitivity tests using these large-scale models will be carried out to assess the impact of these parameterizations.

WORK COMPLETED

During FY02 the analysis of the SHEBA mass balance and ocean heat flux measurements was completed. We developed a basin-scale Lagrangian sea ice model running a virtual RGPS. This model was used to generate detailed simulations of the SHEBA winter. Several journal publications were prepared and submitted and we helped organize a SHEBA workshop. We served as a guest editor, and as authors, for a SHEBA special section of the Journal of Geophysical Research.

RESULTS

The analysis of the SHEBA snow and ice observations has produced interesting insights regarding the mass balance of the ice, the time-averaged ocean heat flux, light transmission through the ice, and the partitioning of the incident solar radiation. A newly developed discrete element model of the Arctic ice cover is incorporating these insights in its treatment of thermodynamics.

Observations of sea ice mass balance and temperature made during the year-long Surface HEat Budget of the Arctic Ocean (SHEBA) field experiment were used to calculate monthly estimates of the ocean heat flux (F_w) for a variety of ice types (Figure 1). All sites exhibited the same strong seasonal cycle. F_w was only a few W m^{-2} from November until May, with one brief exception. The exception was a storm- and topography-induced upwelling event in March, when the five-day average of F_w reached 37 W m^{-2}. Starting in May, there was a steady increase in the ocean heat flux, reaching a peak in late July and early August. There was significant variability in F_w for different multiyear ice types. The value of 12.1 W m^{-2} for an old ridge was the largest annual average F_w, compared to 7.5 W m^{-2} for undeformed ice and 10.4 W m^{-2} for a melt pond. Peak monthly averages in summer were about 18 W m^{-2} for

undeformed multiyear ice and 32 W m^{-2} for ponded ice and ridged ice. Values of F_w observed during SHEBA were more than twice as large as those measured in 1975 during AIDJEX. Indications are that solar radiation transmitted through the extensive ponds and the relatively thin bare ice at SHEBA contributed substantially to the ocean heat flux.

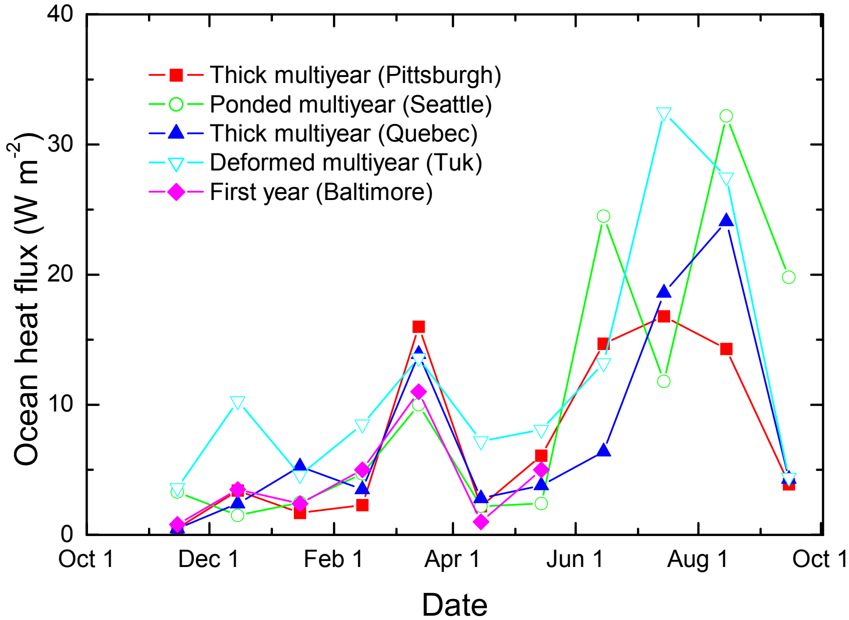

Figure 1. Time series of monthly values of ocean heat flux determined at five sites: thick multiyear ice, ponded multiyear ice, ridged multiyear ice, and first-year ice.

The summer melt cycle of Arctic sea ice is in large part governed by the partitioning of solar radiation between reflection to the atmosphere, absorption in the ice, and transmission to the ocean. Aggregate scale albedos were determined by integrating surface observations of albedo with aerial estimates of areal fraction. Because of the strong dependence of transmittance on ice thickness, transmittances cannot be estimated in a similar fashion to the albedo. Determining the aggregate-scale transmittance must take into account the myriad combinations of snow depths, ice thicknesses, and pond depths present in the ice cover. Snow depth and ice thickness surveys were periodically made along a 600-m-long line. Results from 10 June (Figure 2a) and 7 August (Figure 2b) illustrate the spatial variability in snow depth and ice thickness. The data from these surveys were input to a radiative transfer model and the transmittance was computed (Figure 2c). Between 10 June and 7 August, transmittance increased everywhere along the line. The increase ranged from a factor of three to three orders of magnitude. The large peaks in transmittance are associated with leads and the smaller peaks with melt ponds. Ponds transmitted substantially more light that bare ice, with pond transmittances about 0.1 – 0.2 and bare ice typically 0.02 – 0.04. In essence, leads act as windows to the ocean and ponds act as skylights.

The aggregate-scale partitioning of the incident solar radiation was computed by assuming that the range of snow and ice thicknesses along these lines was statistically representative of the overall region. Prior to the onset of melt at SHEBA, the surface consisted primarily of large, snow-covered, ice floes with only a few percent covered by open water. Approximately 80% of the incident solar radiation was reflected, 17% was absorbed in the snow, and less than 3% was transmitted to the ocean.

As summer melt progressed the surface evolved into a variegated mixture of bare ice, melt ponds, and leads. By August 7, there was approximately 60% bare ice, 20% ponds, and 20% leads. These changes in the composition of the ice cover had a profound impact on the partitioning of the incident solar radiation. Under these conditions, only 45% of the incident solar radiation was reflected, while 33% was absorbed in the ice and contributed to surface and internal melting. The remaining 22% was transmitted to the ocean, where it was available for melting on the bottom and lateral edges of the ice.

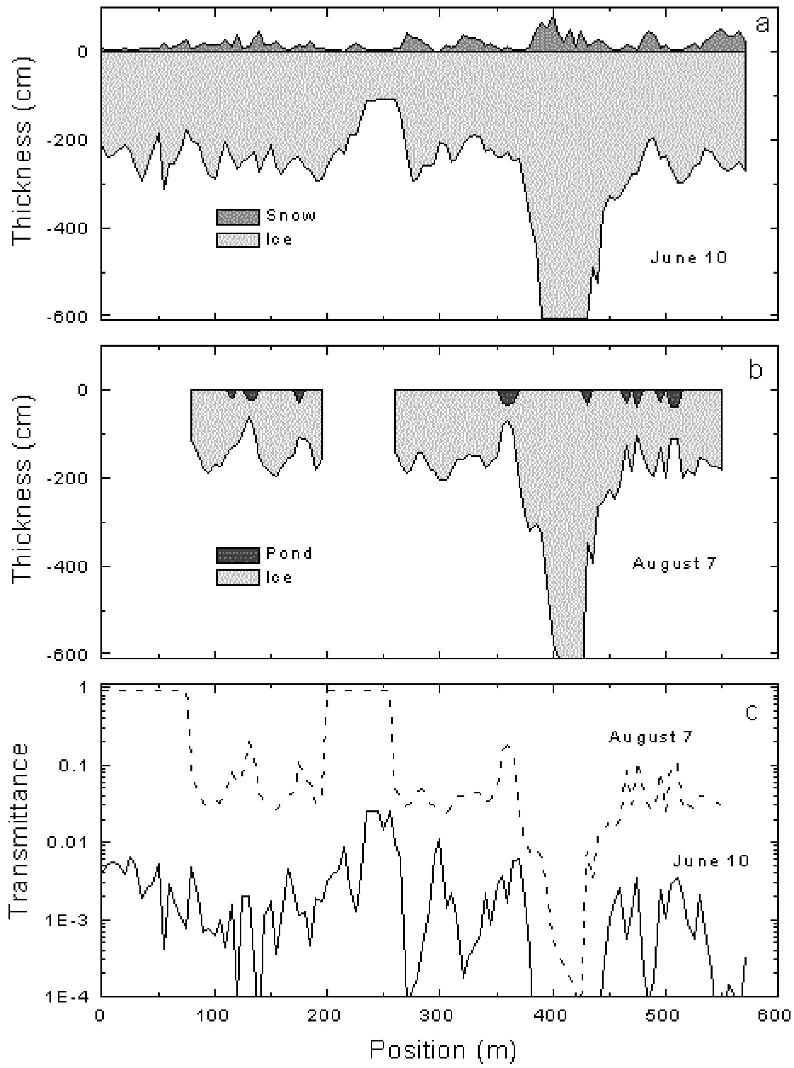

Figure 2. Snow and ice conditions on a) 10 June and b) 7 August and c) transmitted radiation.

The basin scale Lagrangian sea ice model that we have developed consists of tens of thousands of discrete polygonal floes with an average width of 13 km. Deformation of the model ice pack is driven by geostrophic winds and Coriolis forces. Neighboring floes can freeze together, break apart to form leads, and converge to form pressure ridges. Thermal growth and melt are modeled using an algorithm developed by Flato based on the work of Ebert and Curry. SHEBA observations are used to modify the treatment of thermodynamics in the model. The ice thickness distribution of the discrete floes responds to temperature fields, radiative fluxes, and ridging. This year a virtual RGPS was constructed to run on

top of the Lagrangian sea ice model. A map of vorticity from a simulation is shown in Figure 3. Work was begun on developing an approach to use for model validation using direct comparison between simulated maps of divergence, vorticity, shear, and ice motion produced by the virtual RGPS and observed maps produced by the RGPS group at JPL and ASF. An improved wind and water drag formulation was implemented for calculation of air and water stresses using an idealized boundary layer approach with constant turning angles. The underlying discretization used in the Lagrangian sea ice model was converted from a Voronoi tessellation to a Delaunay triangulation for improved modeling of fracture processes. Work was begun on modeling the spring transition between a frozen, consolidated pack and a melting, unconsolidated pack.

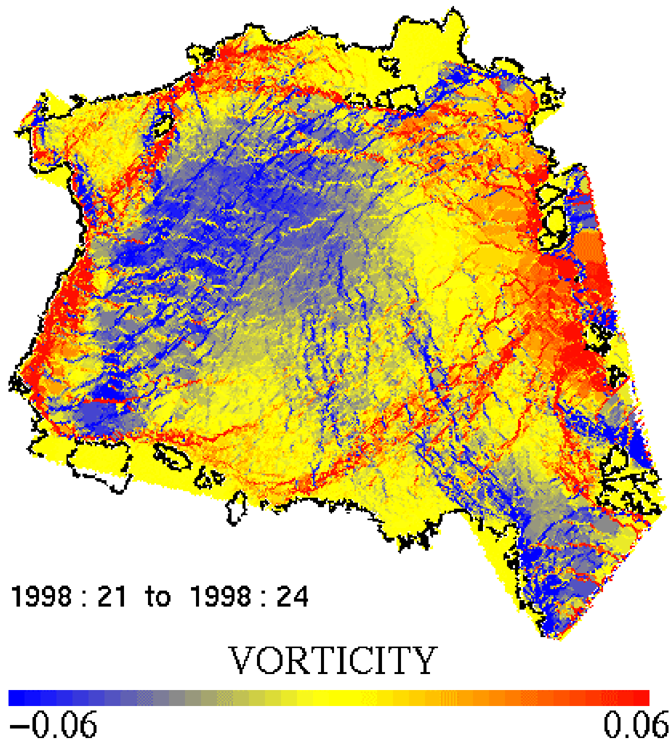

Figure 3. A map of vorticity produced in a simulation of the Arctic ice pack using the Lagrangian sea ice model and a virtual RGPS. Fram Strait is on the right.

IMPACT/APPLICATION

Results from this work are being used to improve the sea ice component of ice forecasting models and of general circulation models. These observations are improving parameterizations of the ice-albedo feedback. Estimates of the aggregate-scale partitioning of the incident solar radiation, derived from observations and radiative transfer modeling, are being incorporated into large-scale models. The granular model allows detailed prediction of the distribution and size of leads and pressure ridges, and the explicit location of the ice edge and marginal ice zone.

TRANSITIONS

Results from our field measurements have been reduced and archived. Over 300 CD-ROM's have been distributed and are being used by atmosphere and ocean researchers, and have been incorporated into the SHEBA column dataset. Over the past year, findings have been disseminated in 8 conference presentations, 6 published journal articles and 10 journal articles in press, and 2 under review.

RELATED PROJECTS

This work on this program is being performed jointly with G.A. Maykut T.C. Grenfell, and B. Light. We are also collaborating with other SHEBA investigators, such as Paulson and Pegau's work on summer leads; McPhee and Morison's upper ocean studies; Curry's aircraft and modeling studies; the Moritz and Bitz modeling efforts; and the atmospheric boundary layer group's heat flux effort. Closely related work on the Lagrangian sea ice model is funded by a NASA grant.

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